Academic

Georgia Tech

University CFD lab uses Siemens Digital Industries Software solution to research rotorcraft aerodynamics and optimization

Product

Simcenter

Business challenges

Improve rotor figure of merit by optimizing blade configurations

Understand how tip of anhedral angle can improve performance

Keys to success

Perform high-fidelity simulations using Simcenter STAR-CCM+

Visualize rotor wake trajectory in flow field and force distributions on the blade

Trim the rotor to match the desired thrust setting

Results

Studied rectangular planforms and swept tapered planforms with and without anhedral

Verified benefit of applying anhedral tip shape for the Sikorsky S-76 rotor

Validated results with experimental and other CFD data

Examined flow field from vortex and downwash at the rotor disk

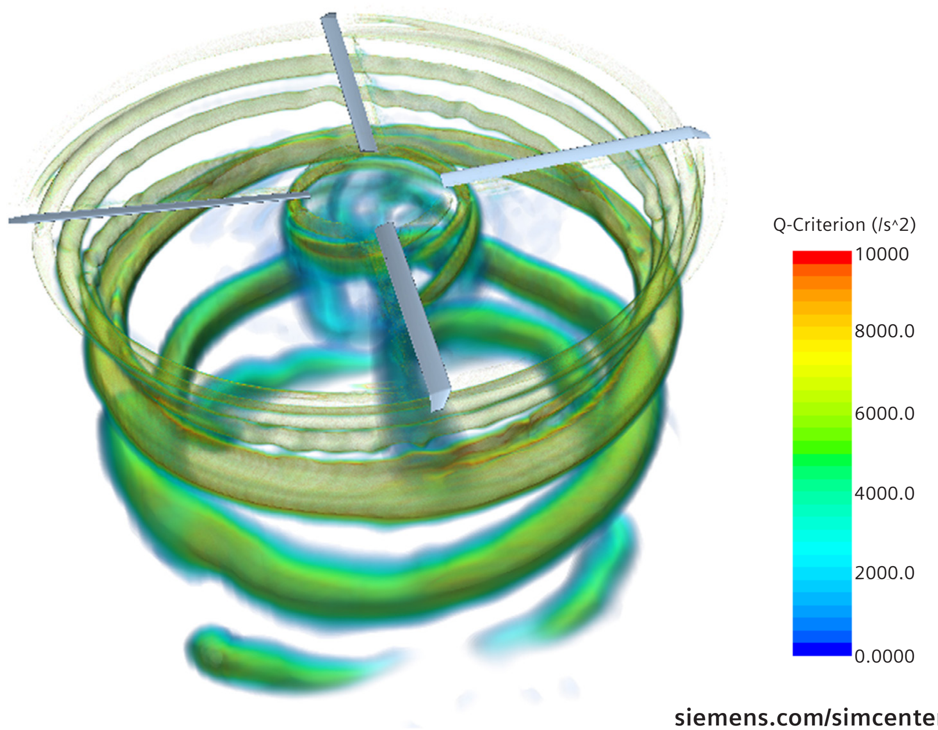
Identified flow mechanisms that improve rotor performance through the addition of tip anhedral

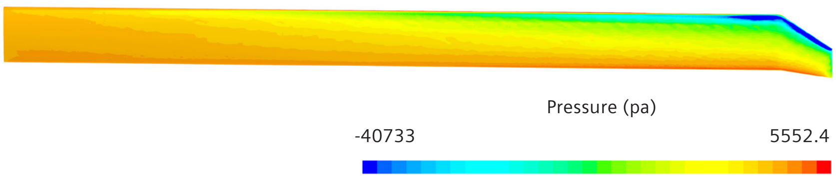
Georgia Tech finds that Simcenter STAR-CCM+ software shows efficient and accurate ways to trim rotors and change tip shapes

Making helicopters more efficient

The helicopter industry has pushed the limits of rotor figure of merit (FM) for decades by optimizing blade configuration and adding active control devices. Over time, people have realized that tip planform plays an important role in rotor performance for both hover and forward flight as well as rotor noise.

Anhedral has been successfully introduced on different blades since the end of the 1990s, such as on the British Experimental Rotor Programme (BERP) blade and the Sikorsky S-76 blade, yet the mechanism of how it improves rotor performance was not completely understood as experimental data is only available for integrated results.





The results from using Simcenter STAR-CCM+ indicate that rotors with anhedral tips experience a slightly greater radial contraction of the tip vortices, causing the tip vortices from the preceding blades to move farther inboard compared to other planforms.

Therefore, flow field visualization and quantification of vortices-blade interaction are important for understanding the detailed flow physics.

In researching this phenomenon, researchers in the Computational Fluid Dynamics Laboratory at the Georgia Institute of Technology found that the Siemens Digital Industries Software solution Simcenter™ STAR-CCM+ software offers an effective way to visualize the flow field and quantify the influence of configuration changes on rotor performance.

Wake-capturing CFD solver in Simcenter STAR-CCM+

The classical Reynolds-Averaged Navier-Stokes solver (RANS) is employed in the simulation to balance memory limitation and accuracy requirements. Central differences are used to estimate the inviscid fluxes with a second order scheme near the rotor blade. Simulations are obtained using a second-order, time-accurate scheme with dual-time subiterations. The air flow is modeled as a compressible, ideal gas. RANS equations are solved simultaneously using implicit spatial integration in an unsteady analysis with a coupled algebraic multigrid method.

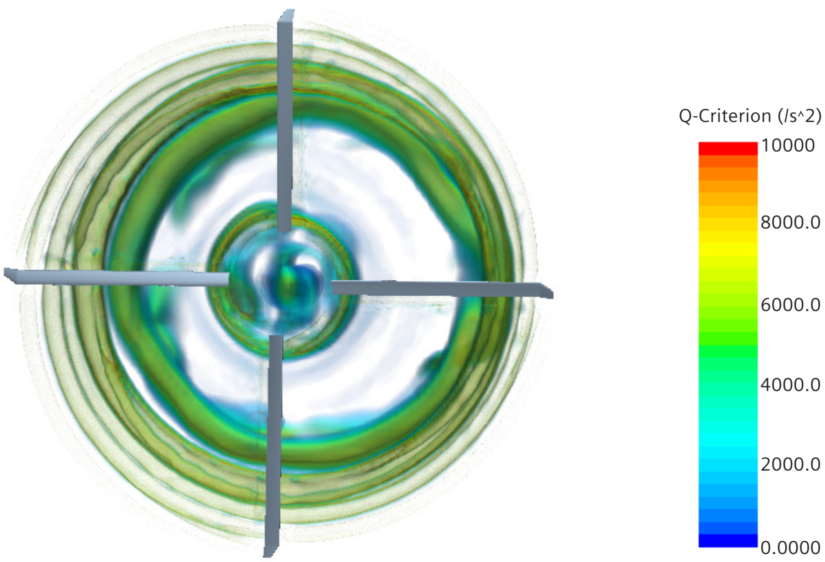
Menter's k-omega SST model is used for turbulence modeling. Other model choices are also available in the software to fit various applications. Because the solution starts from quiescent flow conditions, a starting vortex initially manifests in the flow domain. In order to convect the starting vortex sufficiently away from the rotor, the solution is computed for more than 10 rotor revolutions.

Overset mesh topology

The simulations executed by Simcenter STAR-CCM+ utilize an overset mesh approach. The mesh topology allows users to achieve better accuracy with minimum grid skewness around the blades, and remeshing is not needed during iterations. The stationary background grid is comprised of a single cylindrical block with trimmed hexahedral unstructured elements.

Each rotor blade is enclosed within a cylindrical overset mesh. The near body grid consists of unstructured, trimmed, hexahedral elements which can accommodate blades of complex shapes. The near-body grid is refined at the leading edge, trailing edge and the tip regions using localized volumetric refinement regions to resolve the tip vortices.

Siemens Digital Industries Software solution Simcenter STAR-CCM+ software offers an effective way to visualize the flow field and quantify the influence of configuration changes on rotor performance.



Simcenter STAR-CCM+ gives a computationally efficient and physically accurate means of trimming the rotor and changing tip shapes by offering a user defined/pre-calculated initial condition which accelerates the overall simulation convergence process.

The near-body grids sweep through the stationary background mesh and interpolations are performed at the overset interface using the distance linear interpolation method. The coupling between the background and the overset cells is fully implicit.

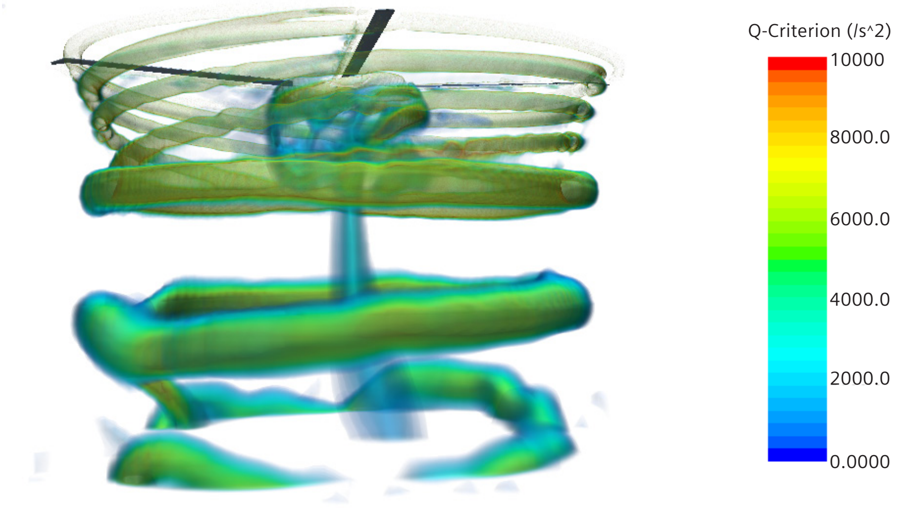
Circulation distribution on rotor blade and wake vortex analysis

The non-dimensionalized circulation distribution along the blade has been calculated from the computed CFD loads at a fixed thrust setting. It was apparent from postprocessing that the rectangular rotor and the swept tapered rotor have a rapid variation in the blade, loading around 90 percent radius. The anhedral tip, on the other hand, shows a more gradual variation in blade loading (and bound circulation).

Simcenter STAR-CCM+ offers a convenient way to visualize the force distribution on a blade and its decomposition into shear, spanwise, and normal force and force components.

Based on Biot-Savart Law, changing of load distributions will cause a rapid variation in the bund circulation. This, in turn, will contribute to a strong trailing vortex. The anhedral tip shows a more gradual variation in blade loading (and bound circulation). This gives rise to a much weaker, more diffused vortex structure. This phenomenon may be visualized using the plane isosurface feature in Simcenter STAR-CCM+. The data is portable from the software to other visualization tools.

Simcenter STAR-CCM+ offers a convenient way of visualizing the force distribution on a blade and its decomposition into shear, spanwise, and normal force and force components.



Solutions/Services

Simcenter STAR-CCM+
siemens.com/simcenter

Customer's primary business

The Georgia Tech aerospace program has a strong computational fluid dynamics research program in fixed- and rotary-wing applications from incompressible through hypersonic speed regimes. The aerodynamics and fluid mechanics (AFM) group focuses its research on the fluid flow around and within aircraft, rotorcraft, planetary entry vehicles, engines and other complex systems.
www.ae.gatech.edu/aerodynamics-and-fluid-mechanics-0

Customer location

Atlanta, Georgia
USA

From the results, the tip vortex of the anhedral configuration is diffused more compared to other configurations, suggesting that tip vortex strength is highly related to the anhedral angle.

Current status and future plans

A systematic study of the effects of tip shape on hover performance of a baseline Sikorsky S-76 rotor has been conducted through Simcenter STAR-CCM+ simulation and the postprocessing process. The simulations and the test data all indicate that rotors with an anhedral tip achieve the best performance in hover. The underlying physical mechanisms behind this improvement are explored during the process. From the integrated force monitors we can tell that the figure of merit improves as the anhedral angle is progressively increased.

The results from using Simcenter STAR-CCM+ indicate that rotors with anhedral tips experience a slightly greater radial contraction of the tip vortices, causing the tip vortices from the preceding blades to move farther inboard compared to other planforms. It is also observed that the anhedral tip vortices are weaker and more diffused. This was traceable to a smoother radial variation of the blade loading near the tip. Finally, rotors with anhedral tips had a more uniform inflow at the rotor disk.

Additional parametric studies of the effect of anhedral tip shape in hover and forward flight are in progress. Changing anhedral angles to isolate the effect and predicting the relationship between the angle of the anhedral tip and the benefits in figure of merit are the next steps in the process. Simcenter STAR-CCM+ gives a computationally efficient and physically accurate means of trimming the rotor and changing tip shapes by offering a user defined/pre-calculated initial condition which accelerates the overall simulation convergence process.

Siemens Digital Industries Software

Americas +1 314 264 8499
Europe +44 (0) 1276 413200
Asia-Pacific +852 2230 3333

siemens.com/software

73703-C11 11/18 Y